Applying Benefit Metrics to Street and Parking Lot Applications to Increase the Value of Lighting

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September 11, 2013

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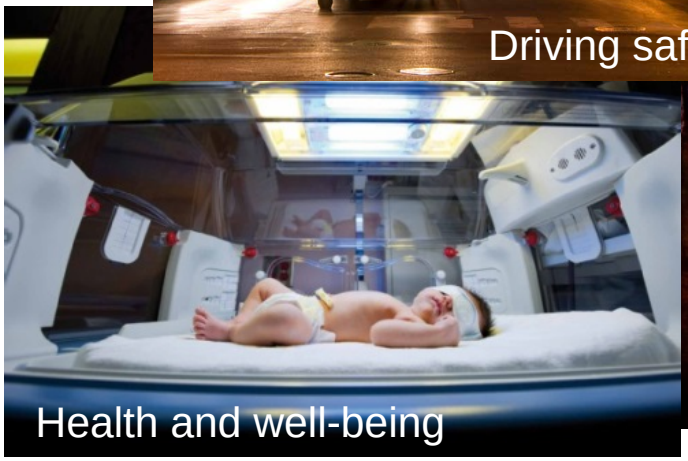
What matters to people is value

Value = benefit/cost

Benefit =

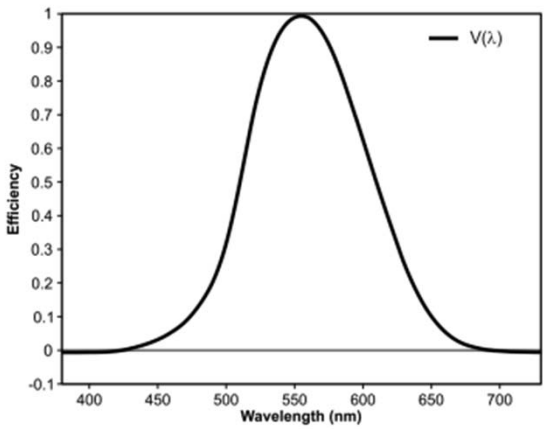


Images: www.osram.com
and www.photos.com

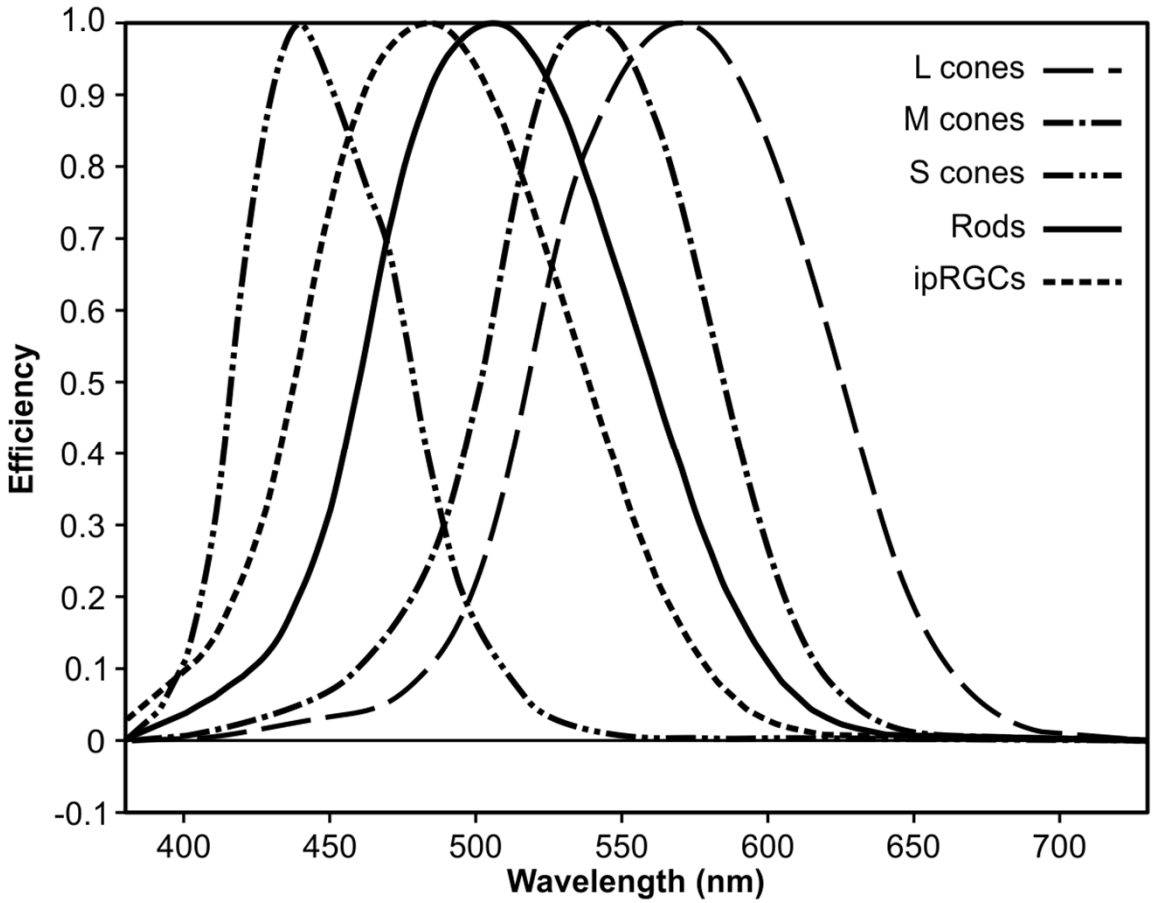
The lumen

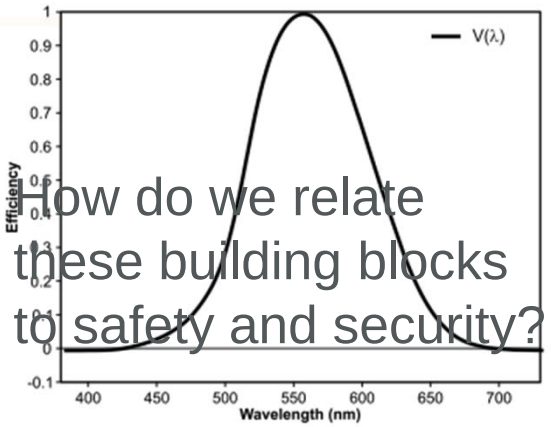
V(λ) has been the foundation for all lighting recommendations since 1924

Barrows WE. 1938. *Light, Photometry and Illuminating Engineering.* McGraw-Hill, NY, p. 420.

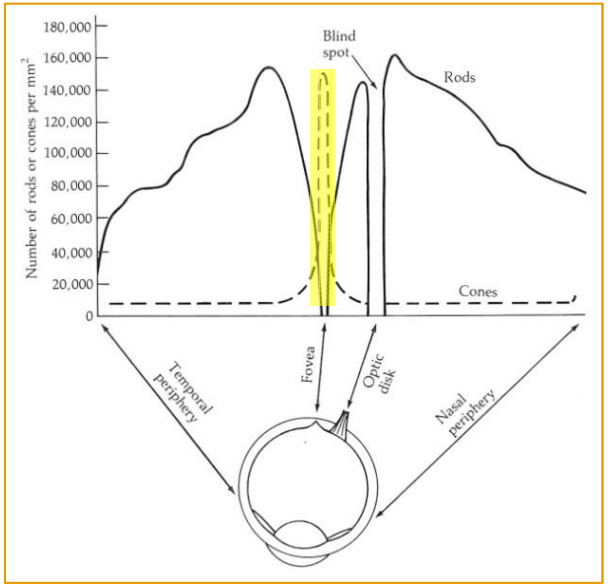


Building blocks for benefit metrics





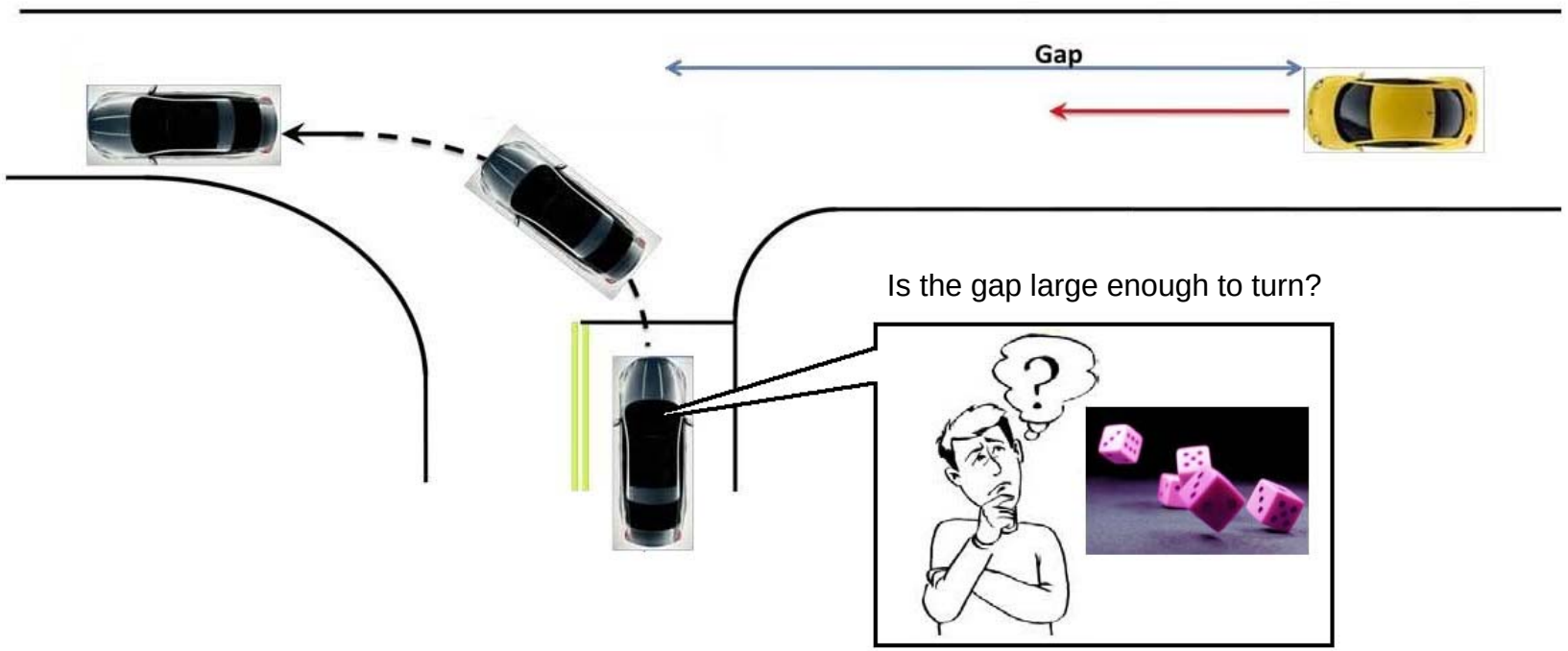
How do we relate these building blocks to safety and security?



Sekuler R and Blake R. 1985. *Perception.* A. A. Knopf, Inc. NY.

Safety: What is the basic problem?

Most crashes are vehicle-vehicle at conflict points (intersections)



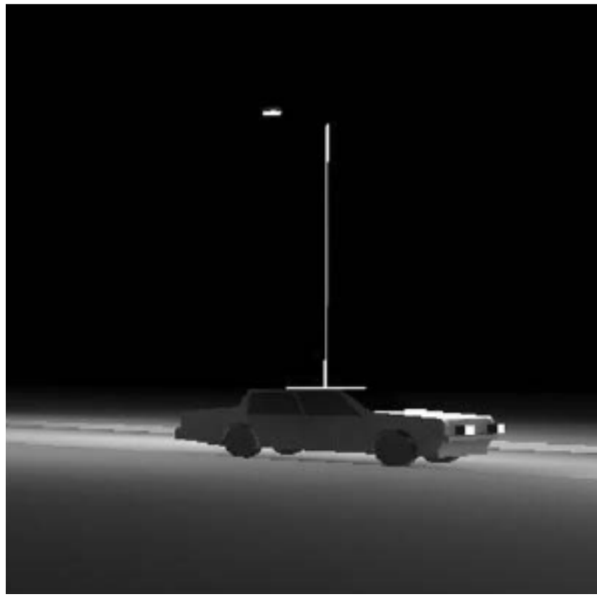
Adapted from connectedvehicle.challenge.gov

Safety: Extracting gap information

Headlamps are highly conspicuous

- So, what's the problem?

Roadway lighting provides both figure/ground information for judgment by the fovea



Rea et al. 2010

Characterizing the lighting in terms of the lumen (L + M cones) should work.

How can we know if lighting matters statistically?

Converging paths

Statistical approach from Minnesota Highway Safety Information System (HSIS) statewide database including lighting and crash data

Analytical approach using visibility coverage areas based on Minnesota DOT practices

Statistical modeling (Donnell et al. 2009)

Multiple nonlinear regression models were developed to predict annual number of daytime and nighttime crashes (C) at Minnesota roadway intersections

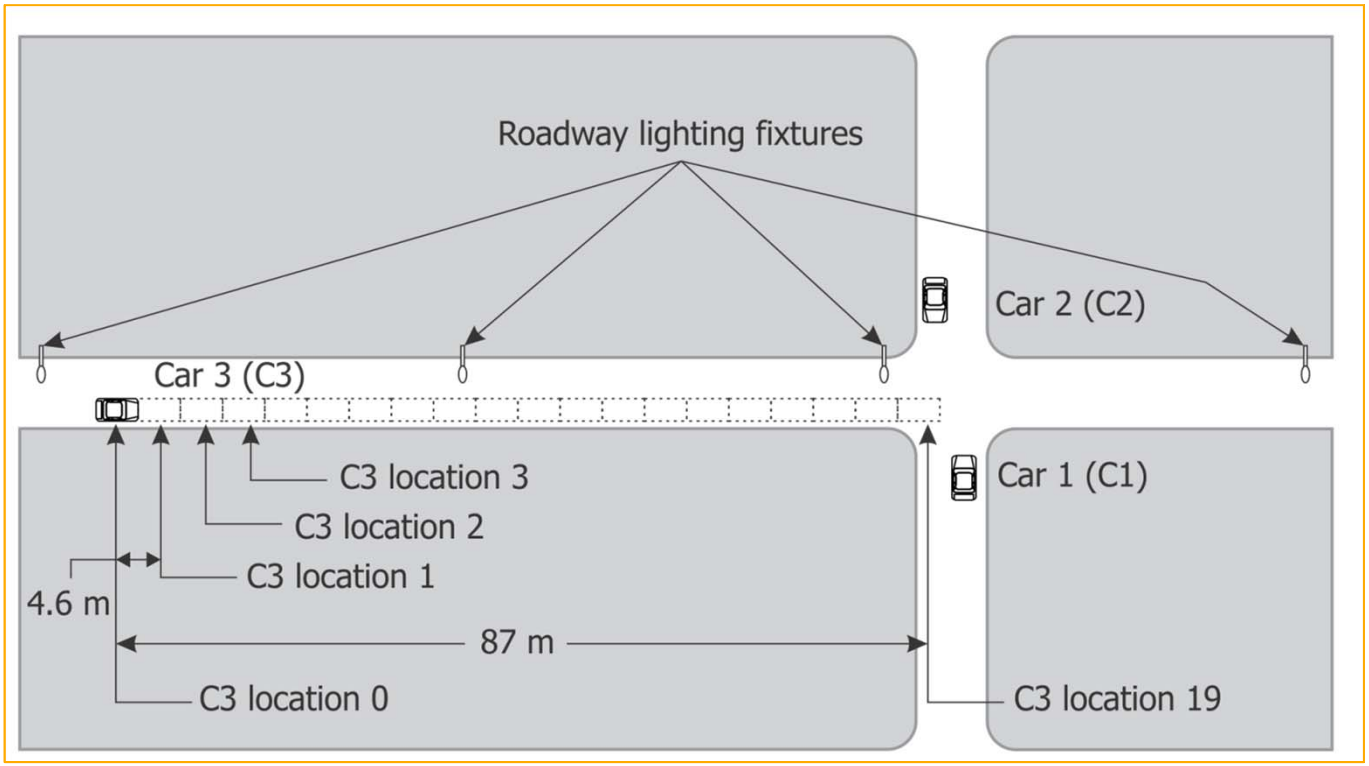
Recognizing that lighting is not randomly allocated to intersections, as many other variables as possible were studied:

- C = f (lighting, traffic volume, urban/rural, signalization, posted speed, % trucks, geometry, access control, median type, left/right shoulder type)

Intersection type	Decrease in night/day crash ratio
Urban signalized	-7%
Suburban unsignalized	-13%
Rural signalized	0%
Rural unsignalized	-2%

How do we analyze visibility?

Visibility coverage area (gap judgment model) using photometric simulations (AGi32)

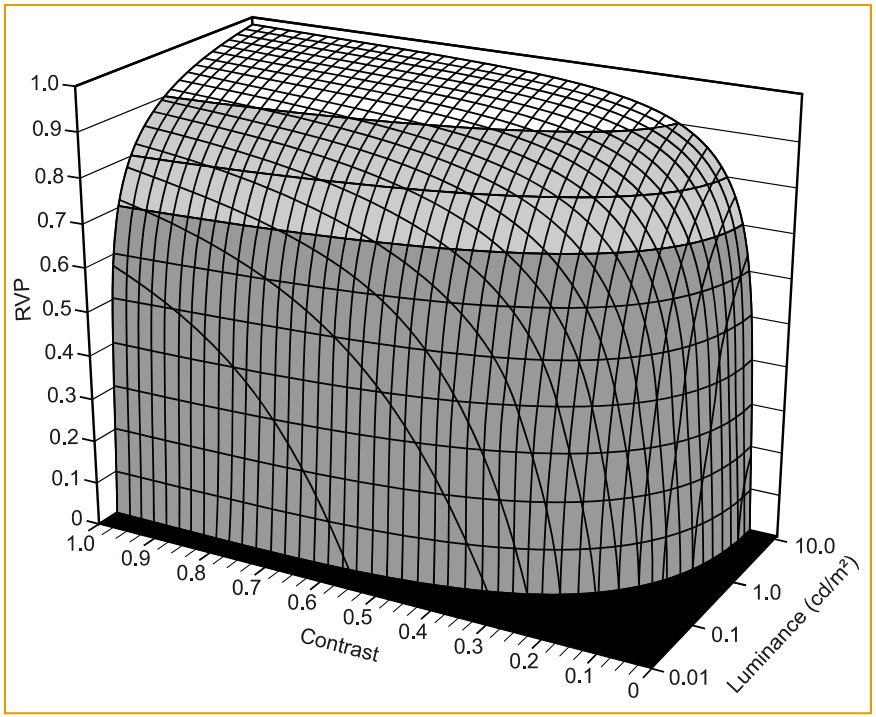


How do we analyze visibility?

Apply relative visual performance (RVP) model

Contrast and background luminance based upon V(λ)

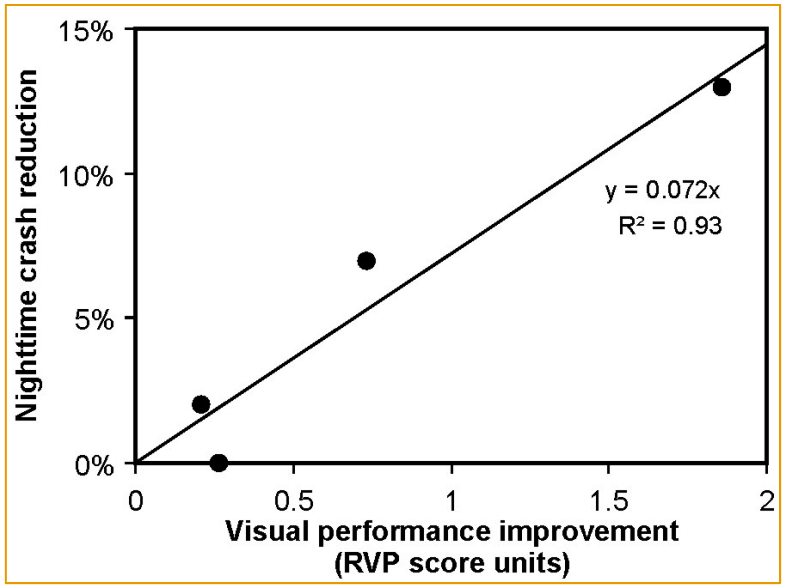
Use IES-defined target for small target visibility (STV)



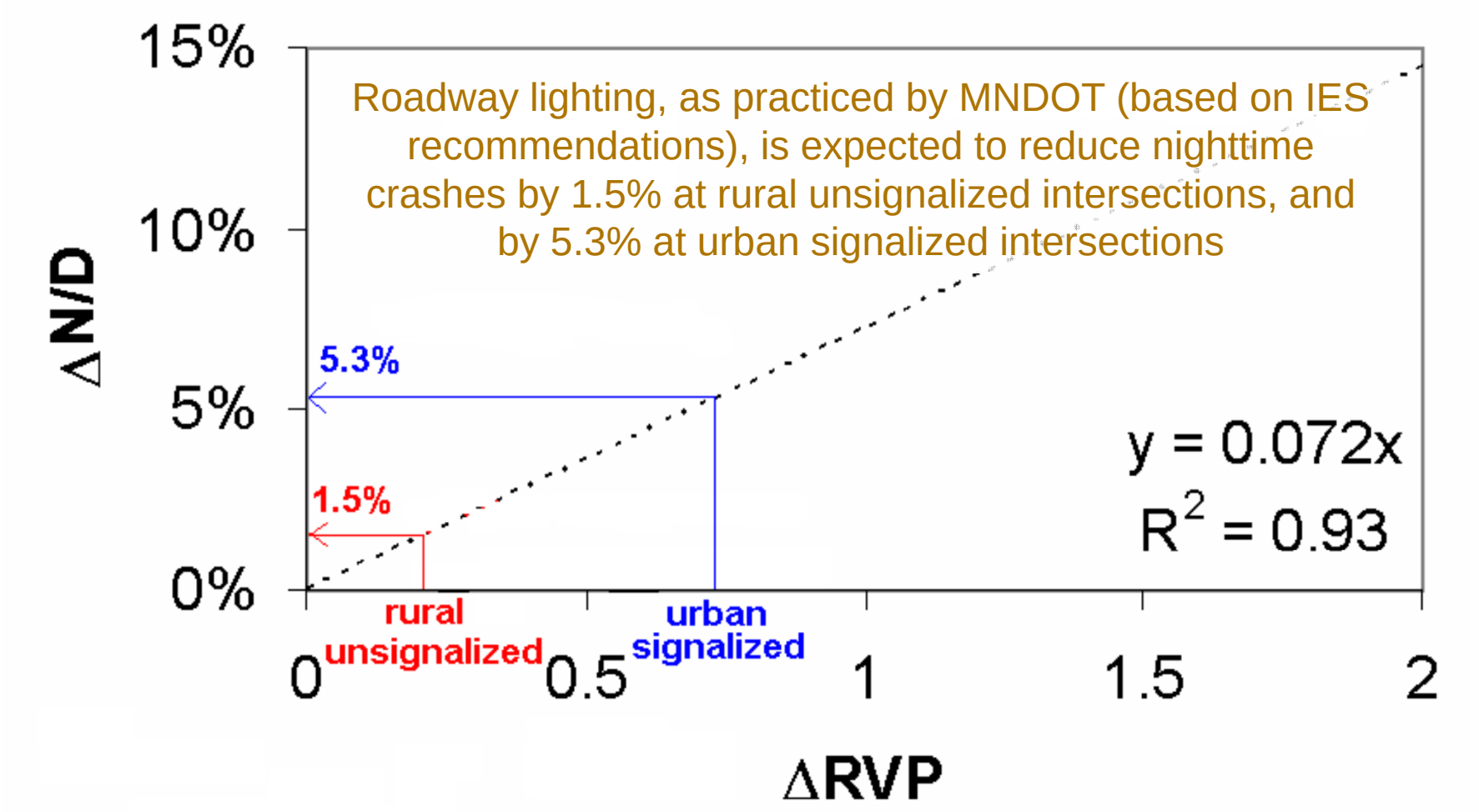
How do the statistical and analytical approaches converge?

Intersections with and without lighting

Intersection type	Decrease in night/day crash ratio	Increase in RVP score
Urban signalized	-7%	+0.73
Suburban unsignalized	-13%	+1.86
Rural signalized	0%	+0.27
Rural unsignalized	-2%	+0.21



Crash reductions vs. change in visibility



How many crashes could lighting reduce each year?

AVERAGE ANNUAL EXPECTED NIGHTTIME CRASHES AT UNLIGHTED INTERSECTIONS

Major Road AADT (annual average daily traffic)	Annual Expected Number of Crashes at Urban Signalized Intersections	Annual Expected Number of Crashes at Rural Unsignalized Intersections
100	0.043	0.032
200	0.065	0.048
500	0.109	0.082
1000	0.162	0.121
2000	0.242	0.181
5000	0.409	0.306
10,000	0.609	0.455
20,000	0.906	0.677
50,000	1.533	1.146

5.3% of these values

1.5% of these values

What does a crash cost?

U.S. DOT (2008) estimates for different crash severity:

- Fatal: $5.8 million
- Incapacitating injury: $401,538
- Evident injury: $80,308
- Possible injury: $42,385
- Property damage only: $4,462

Fatal and injury crashes are more prevalent at rural locations (higher speeds), so the average weighted crash costs are:

- Urban signalized intersections: $122,056
- Rural unsignalized intersections: $232,142

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How much does roadway intersection lighting cost?

Installation cost of dedicated poles with underground wiring (RS Means, 2008)

- Urban signalized: $13,500 (annualized over 20 yr: $1080)
- Rural unsignalized: $4,600 (annualized over 20 yr: $370)

Operation and maintenance cost:

- Urban signalized: $710 (annual)
- Rural unsignalized: $230 (annual)

Overall annual(ized) cost:

- Urban signalized: $1,790 (annual)
- Rural unsignalized: $600 (annual)

Cost is unrelated to traffic volume

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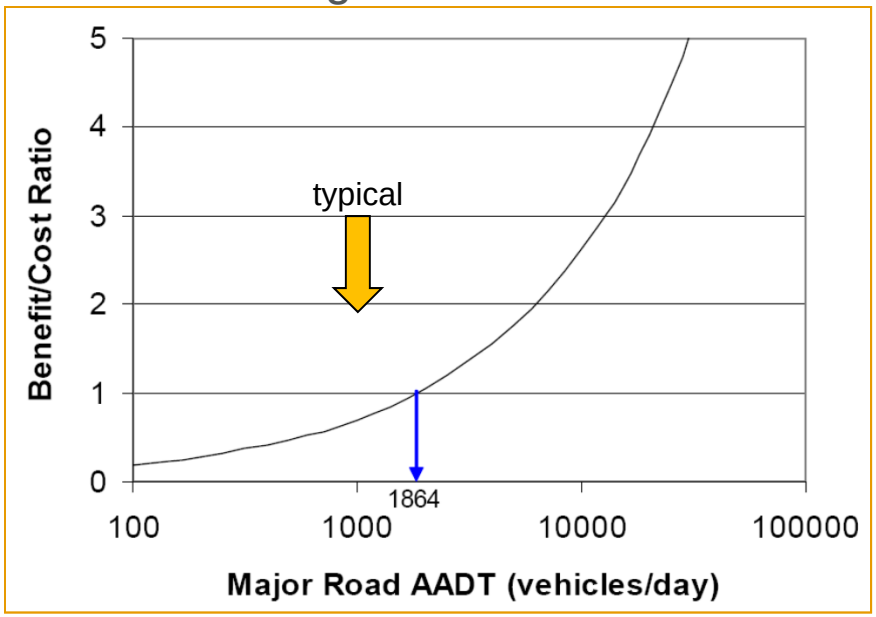
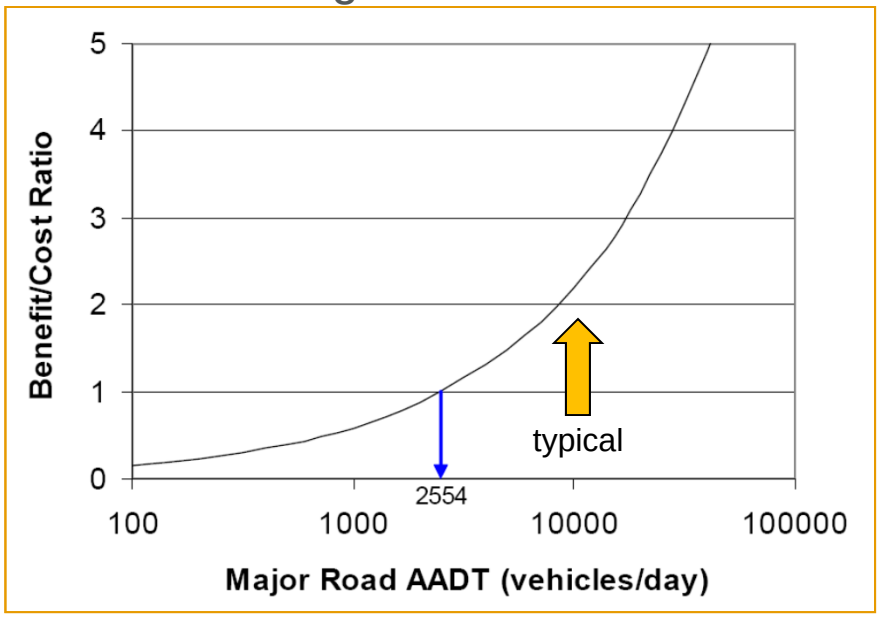
Benefit/cost analysis

Lighting has the same cost whether anyone uses it

Rural unsignalized intersections

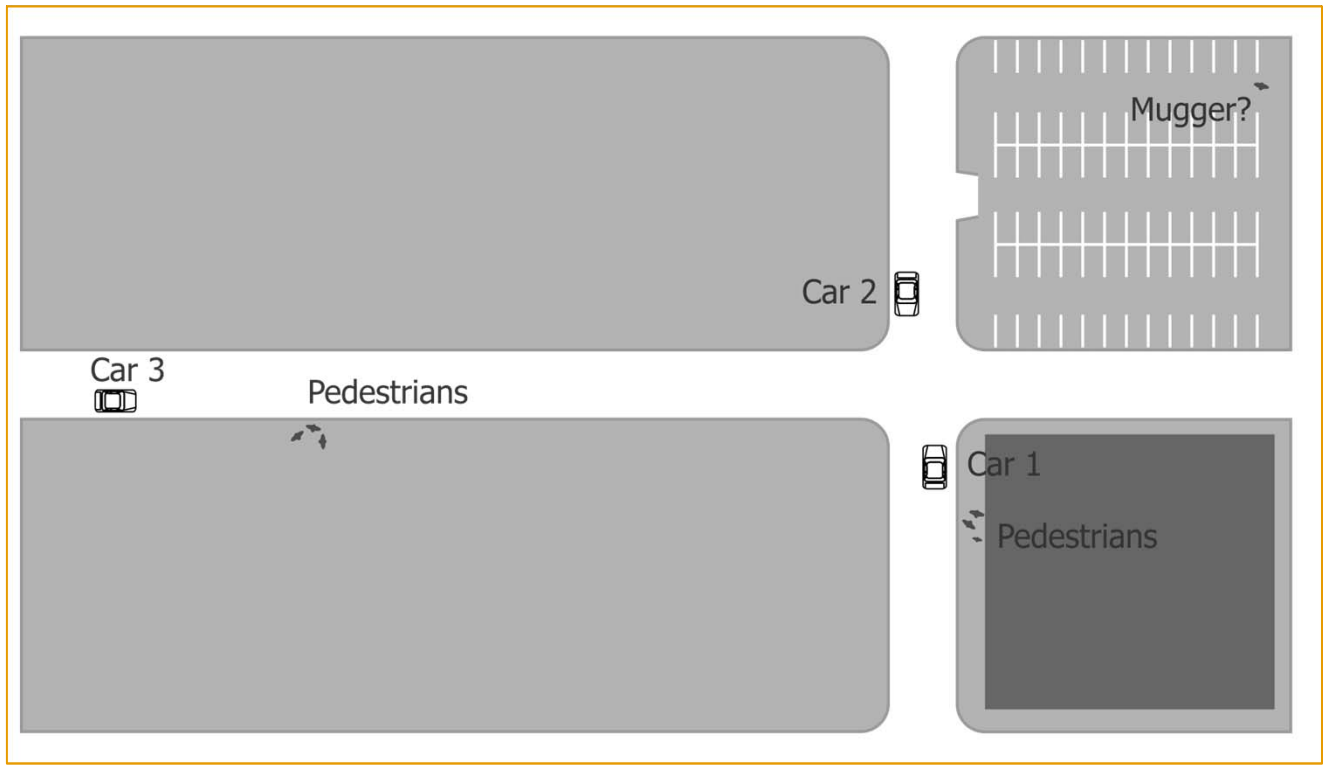


Urban signalized intersections



So, how should we illuminate?

Benefit: Safety (on-axis gap judgment)



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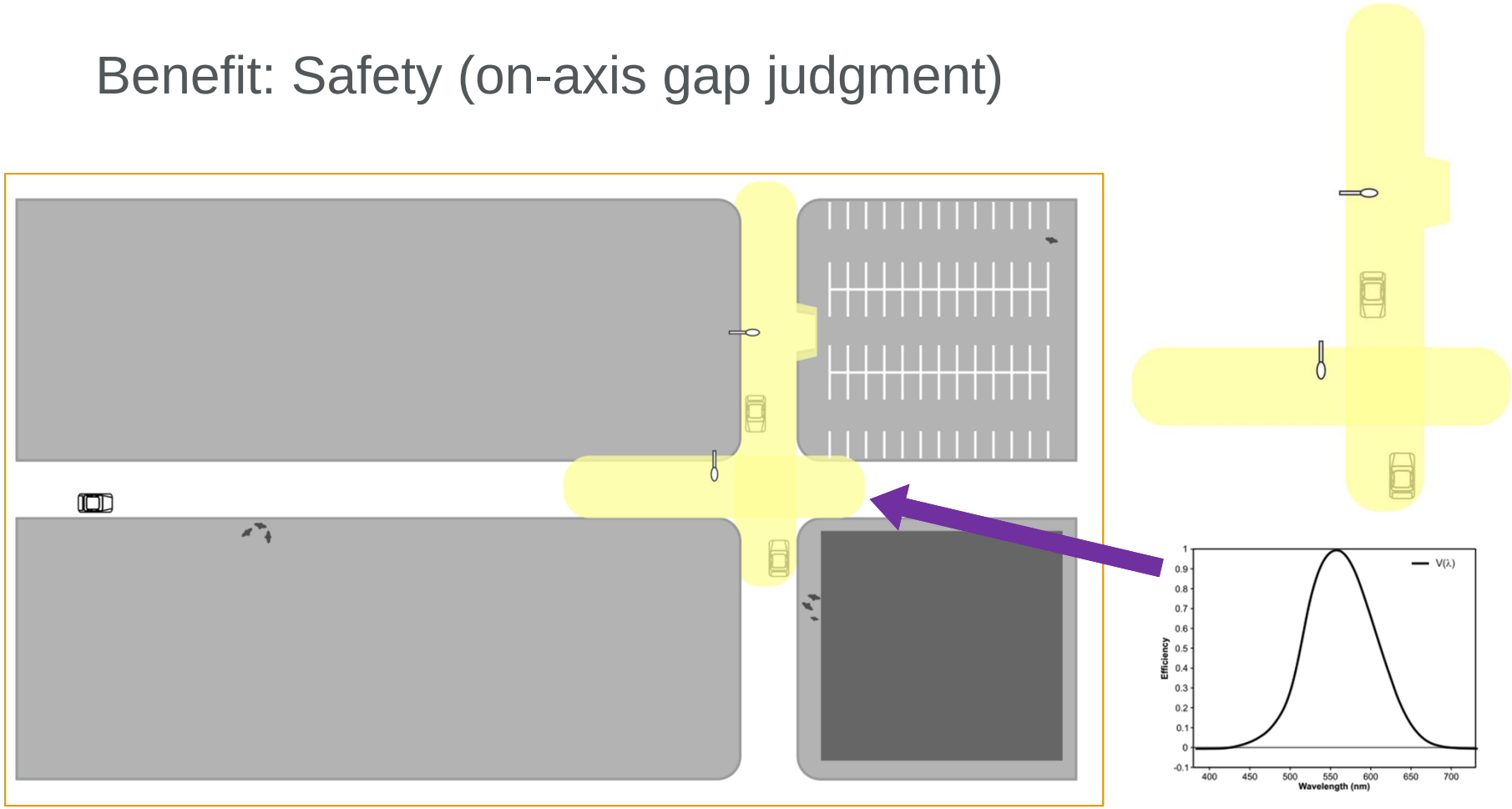


L + M cones

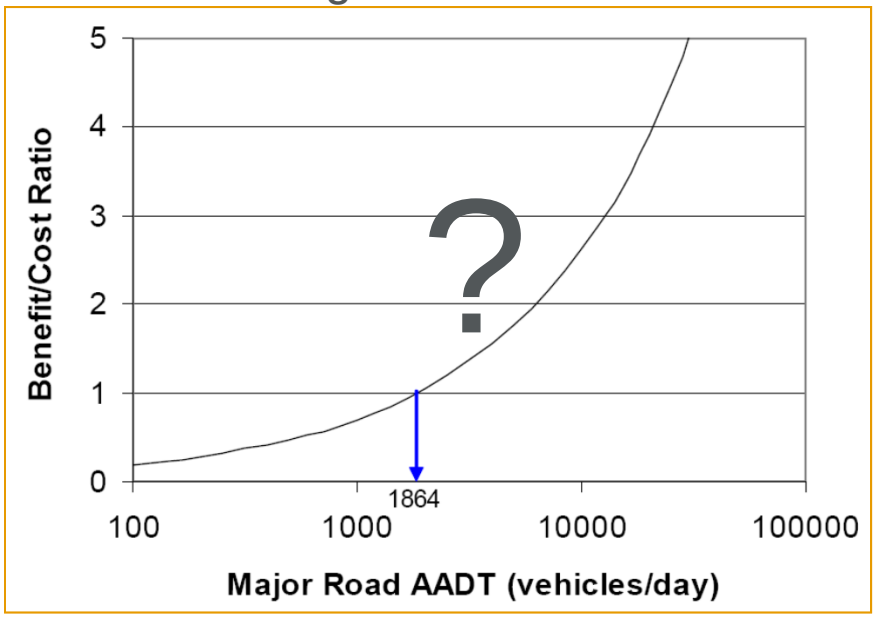
Safety: What is the (other) basic problem?

Off-axis pedestrian detection

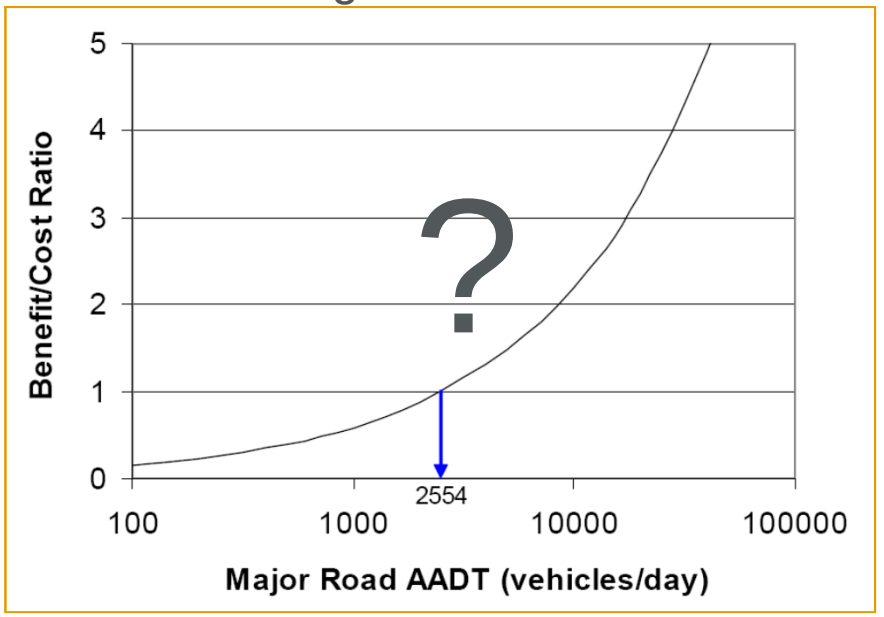
Benefit/cost analysis: Off-axis detection

No complete data set like that for on-axis gap judgment

Rural unsignalized intersections

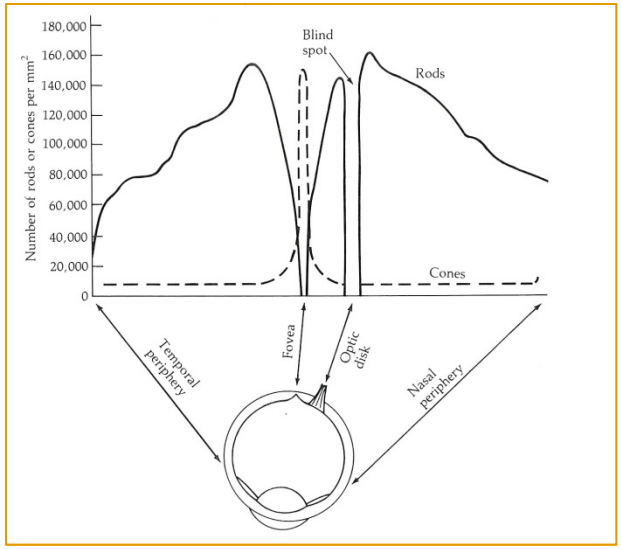


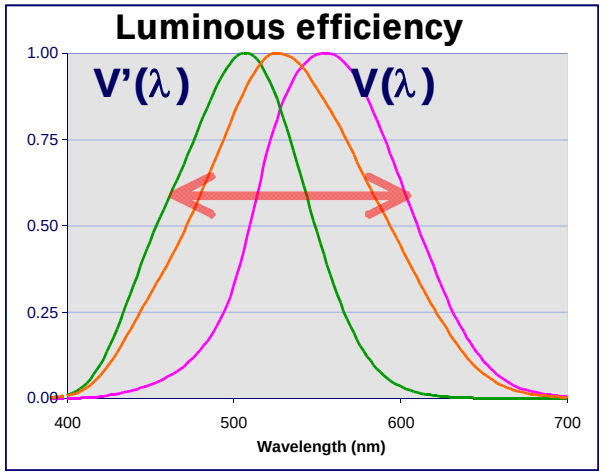
Urban signalized intersections



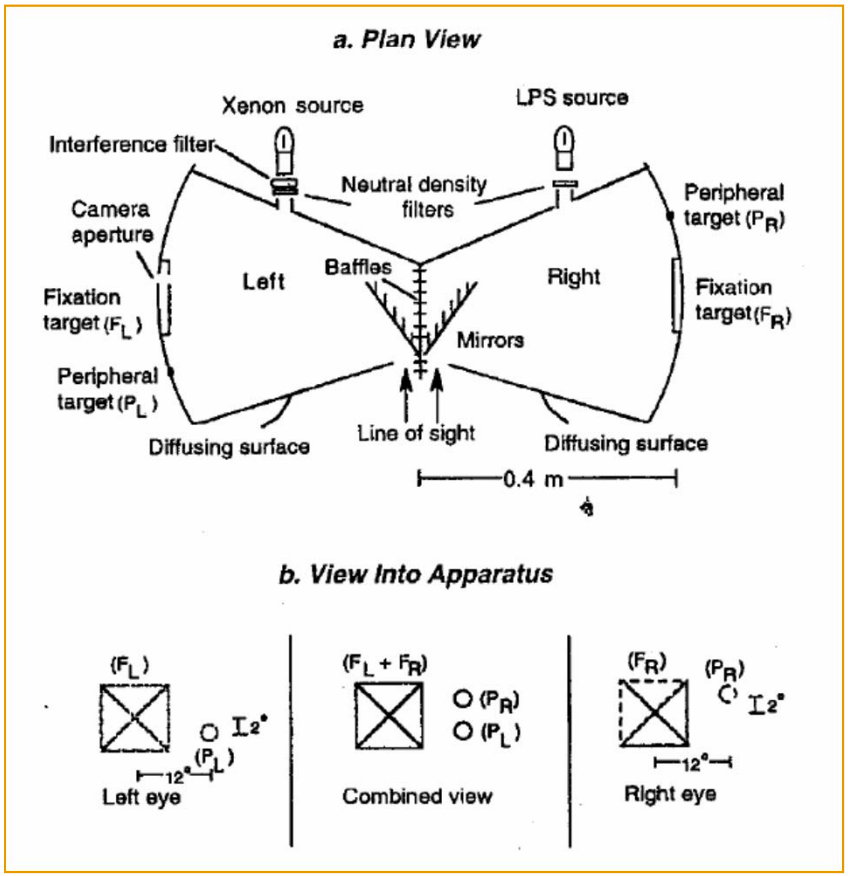
Need estimated benefits of avoided pedestrian collisions
Lighting system costs are easily calculated

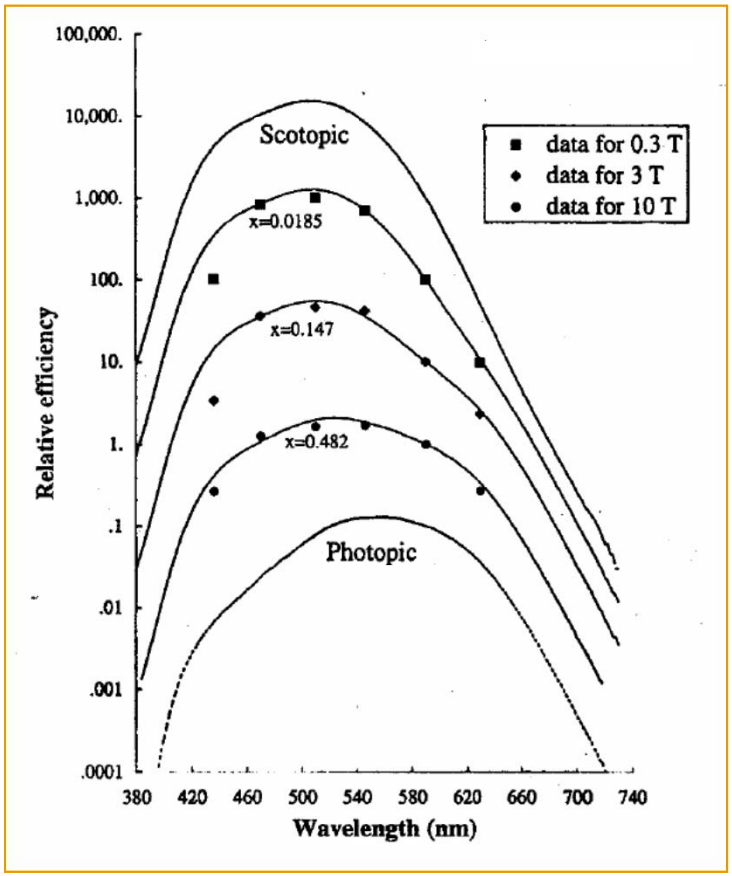
Off-axis detection





A system of mesopic photometry

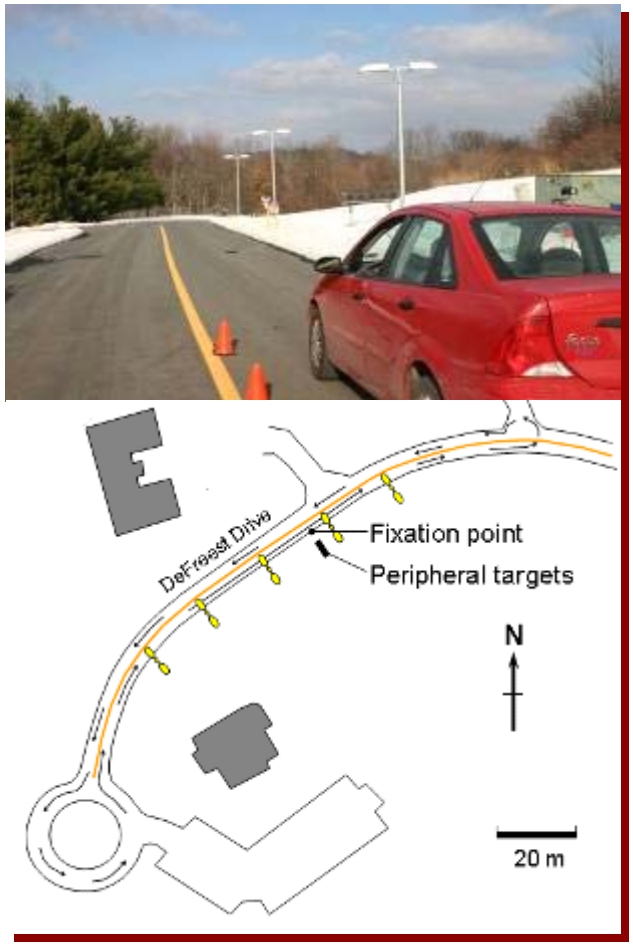




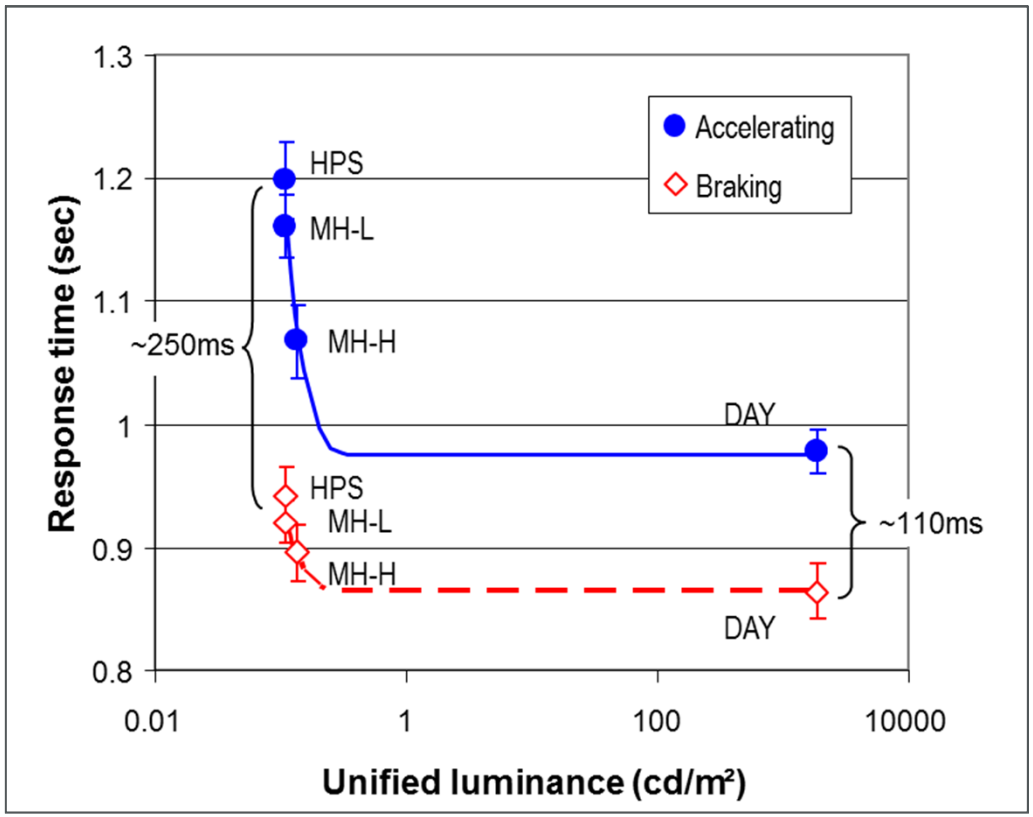
He et al. 1998

Sponsors: DOE, GE, OSRAM Sylvania, Philips, Venture

Driver decision-making (off-axis detection)



Akashi et al. 2007

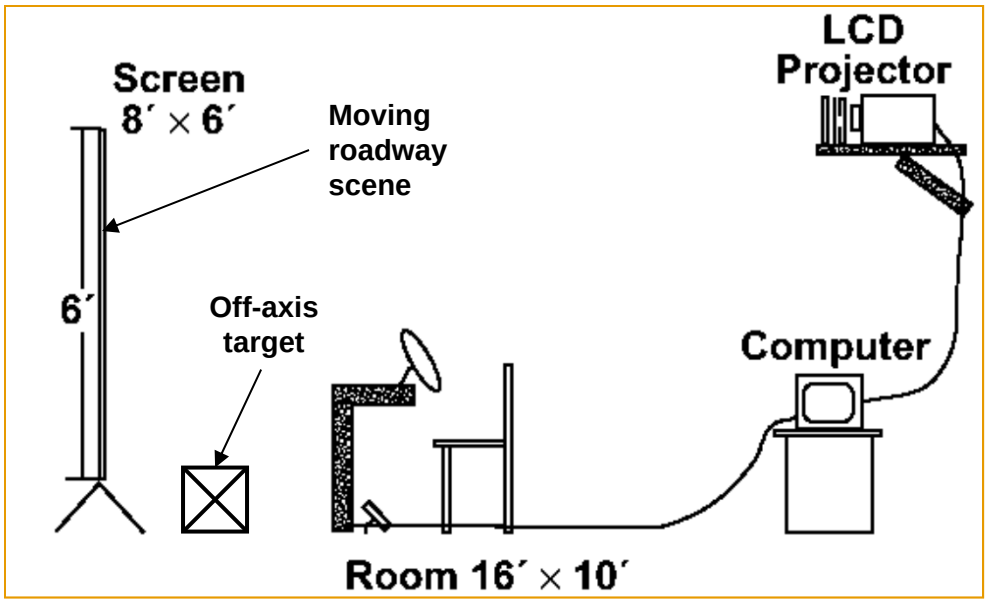


Sponsor: Philips Lighting

6 lux: HPS, MH-H
3 lux: MH-L

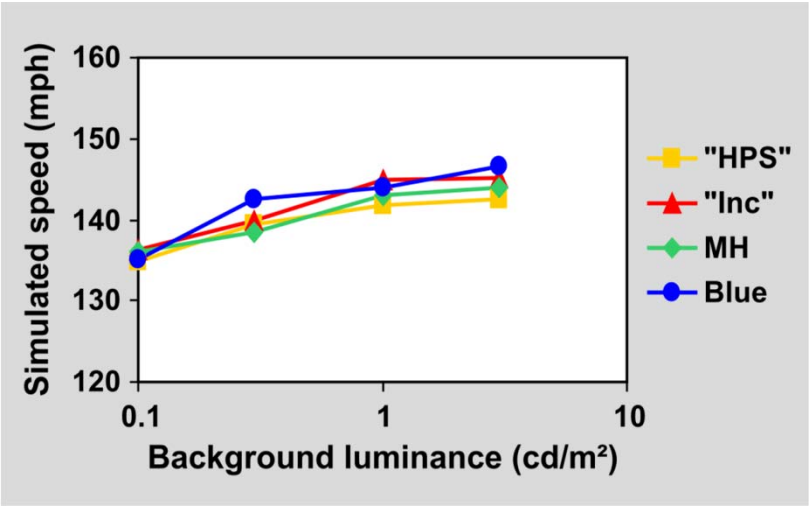
Characterizing the lighting in terms of the lumen will NOT work.

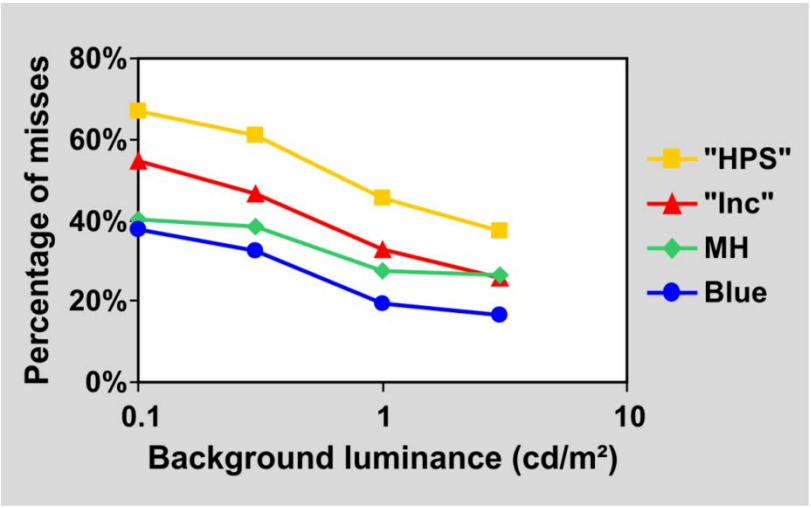
Simulated driving performance



Bullough and Rea 2000

Sponsors: DOE, GE, OSRAM Sylvania, Philips, Venture





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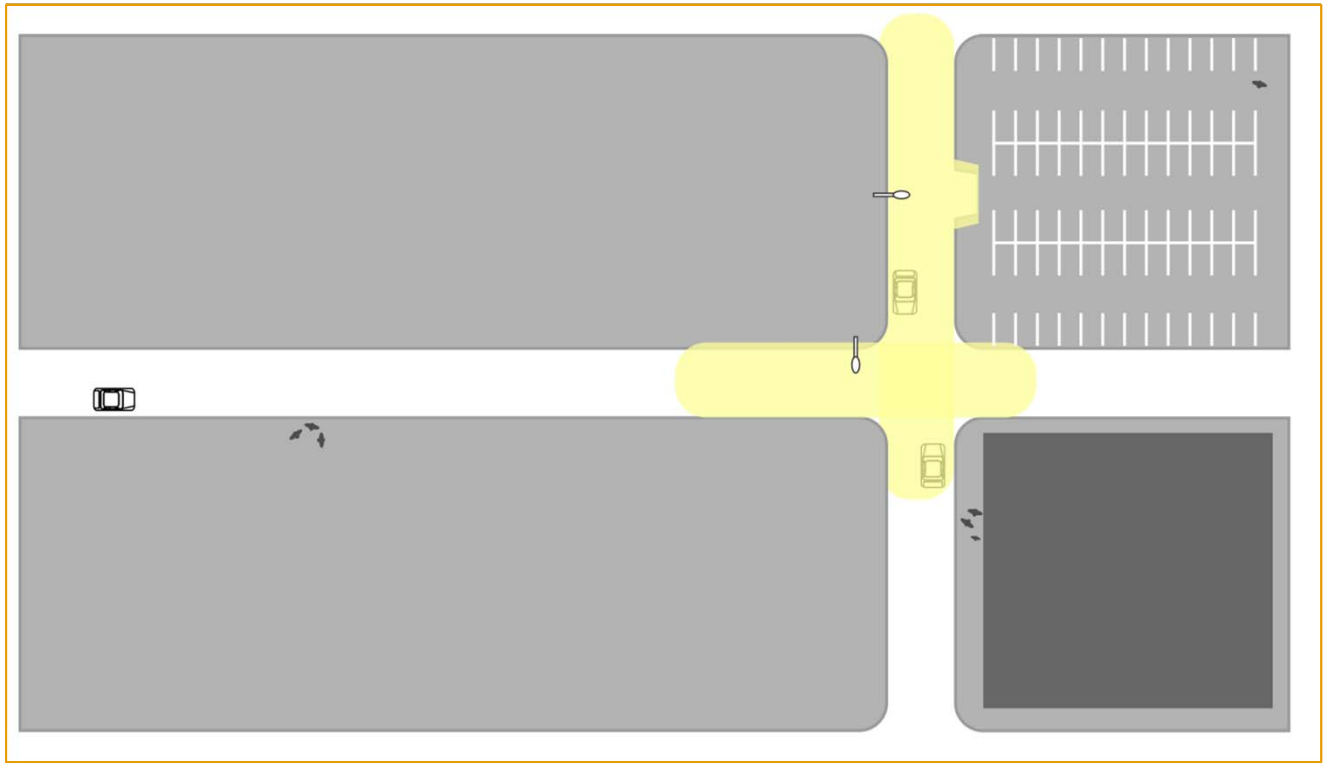
Benefit: Safety (off-axis detection)



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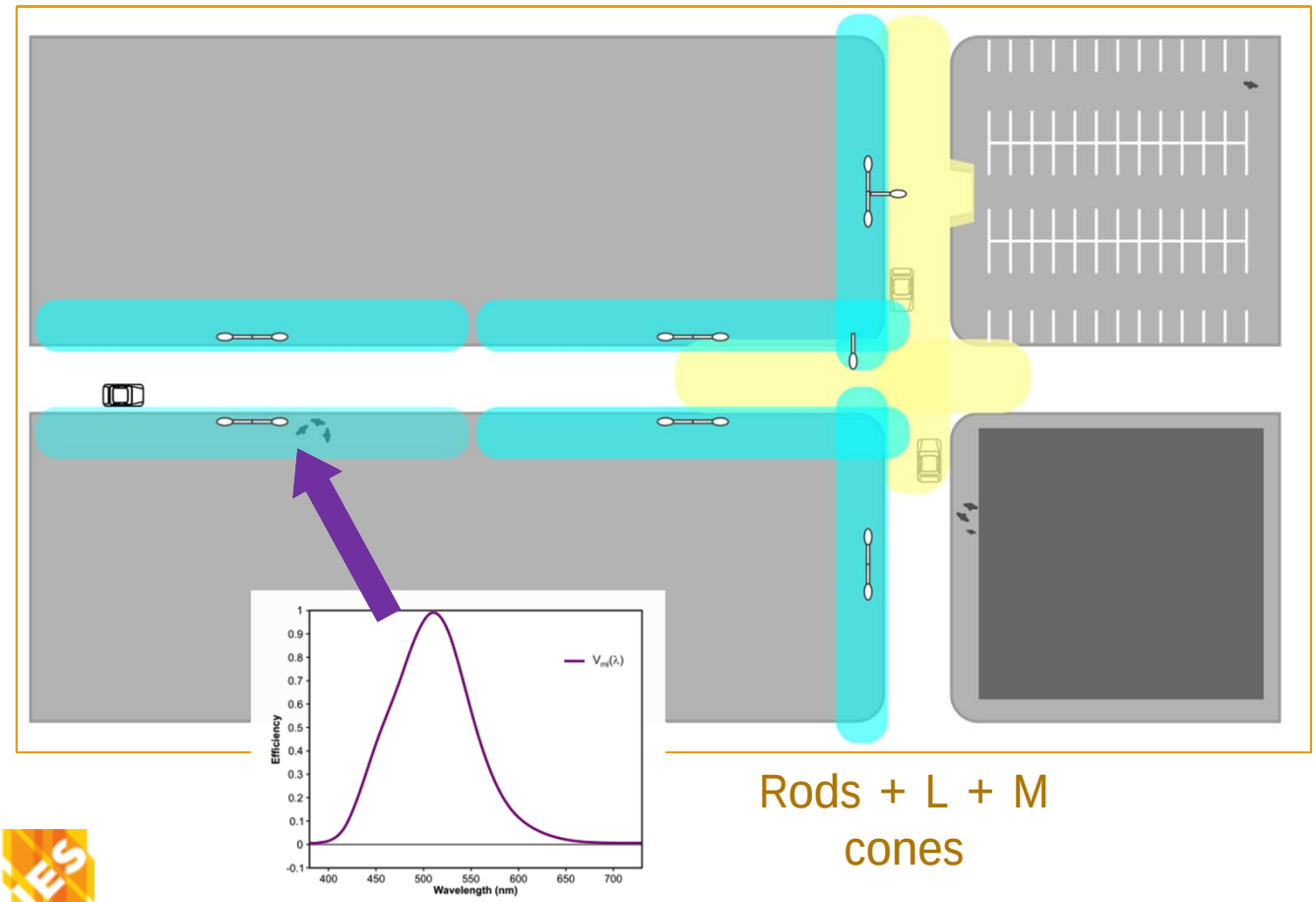
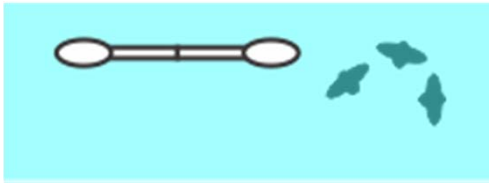
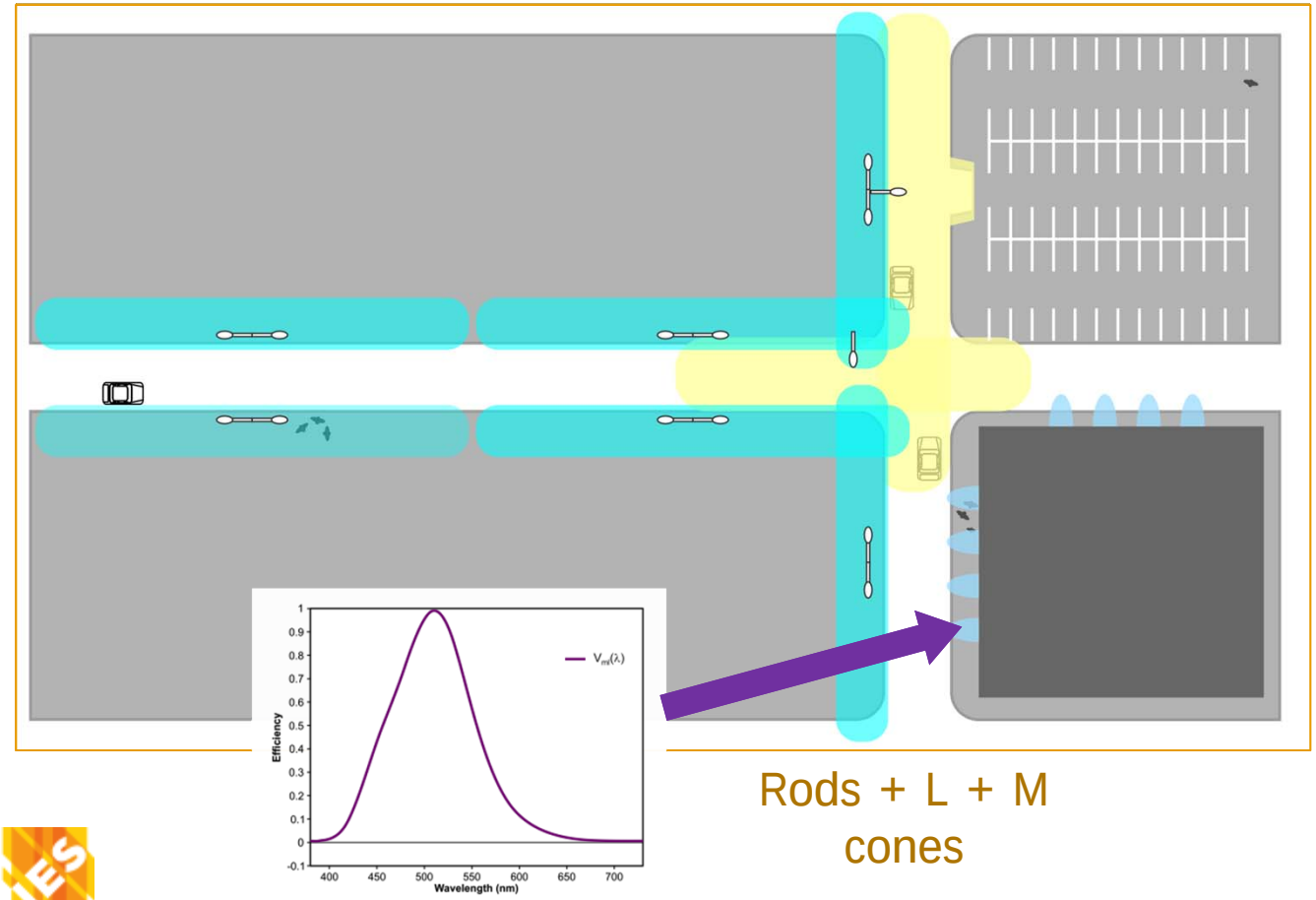




Rods + L + M cones

So, how should we illuminate?

Benefit: Safety (off-axis detection)



Rods + L + M cones

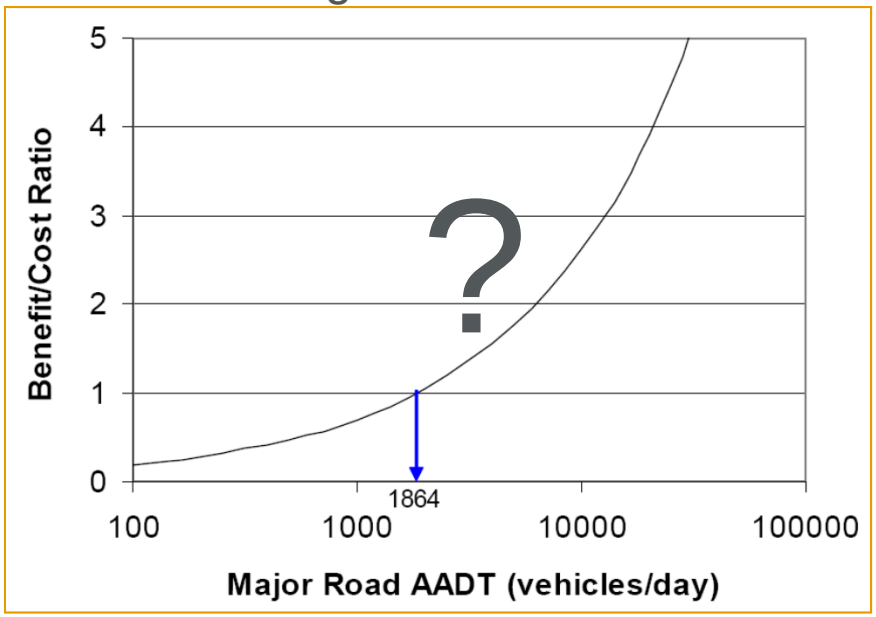
Security: What is the basic problem?

Personal security

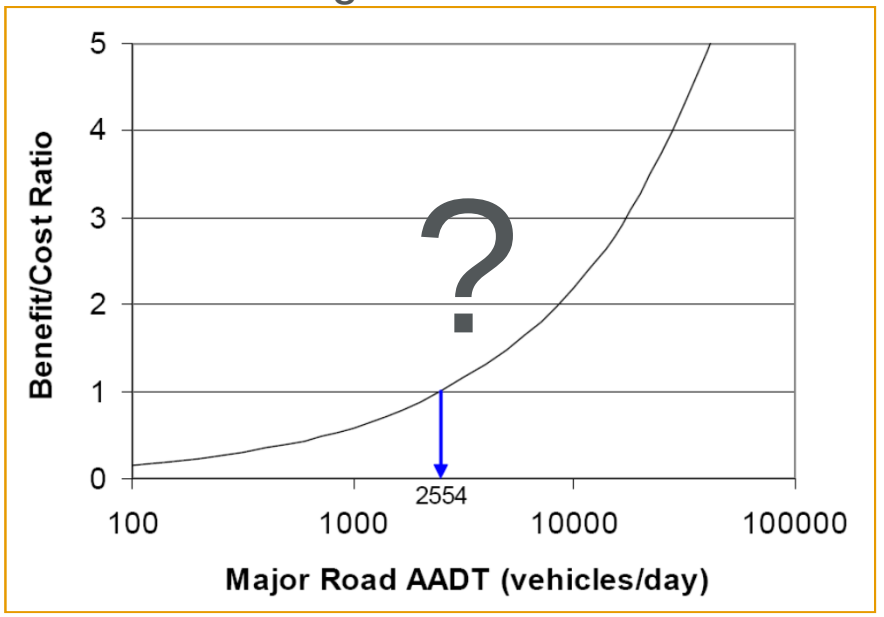
Benefit/cost analysis: Personal security

No complete data set like that for on-axis gap judgment

Rural unsignalized intersections

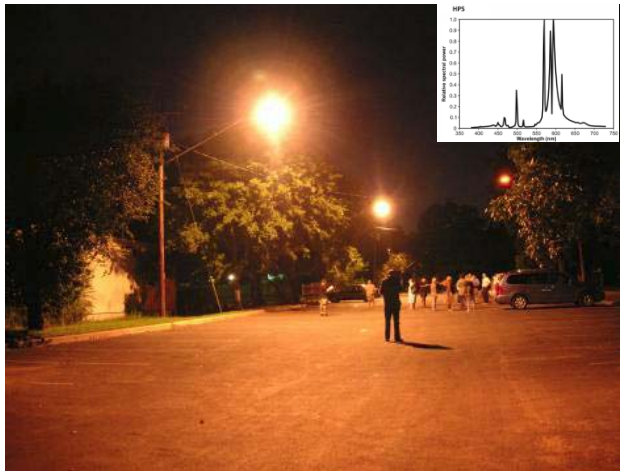


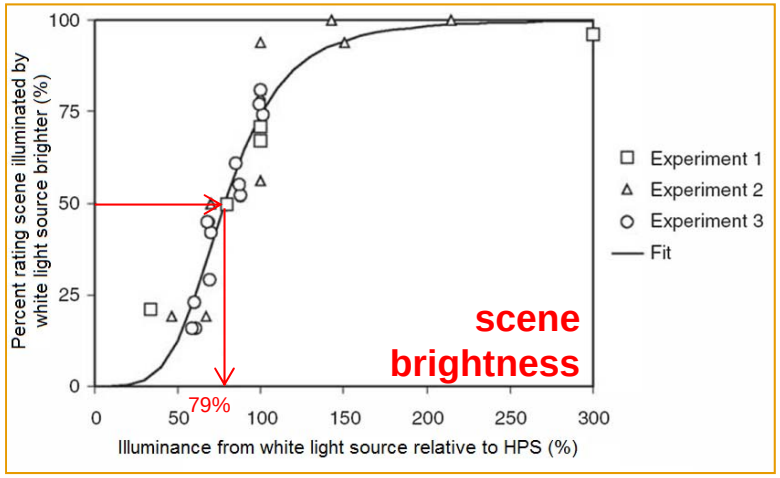
Urban signalized intersections



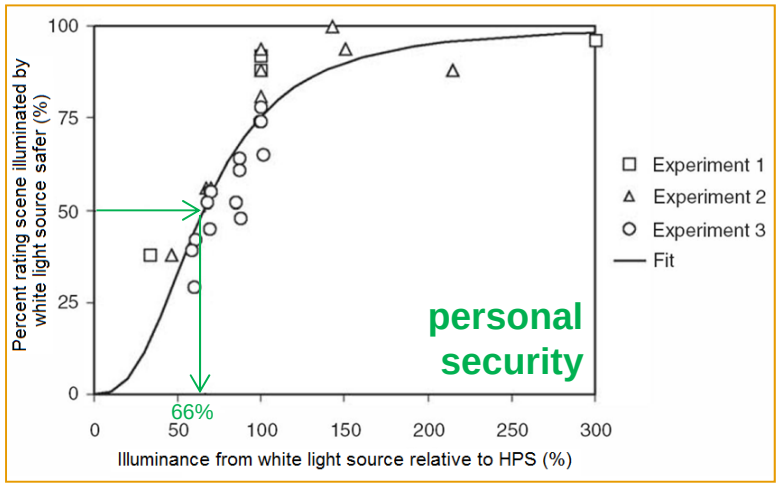
Can estimate equivalent benefits for different light sources
Lighting system costs are easily calculated

Brightness and personal security



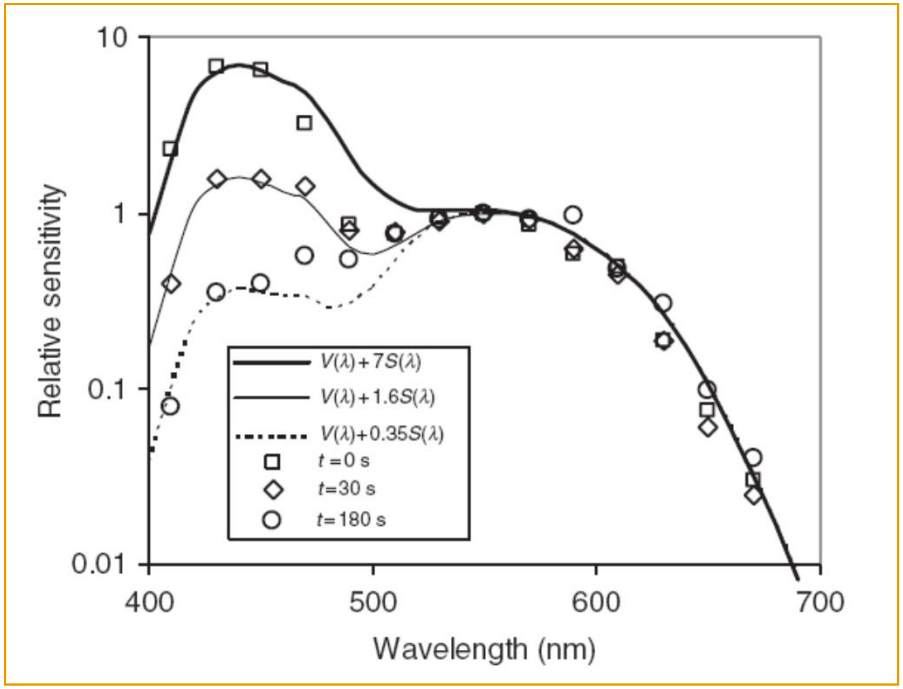


Locations that appear **brighter** tend to be judged as **safer** (Rea et al. 2009)



Therefore, **scene brightness** can be used as a lighting metric for **personal security**

Modeling scene brightness



Rea et al. 2010

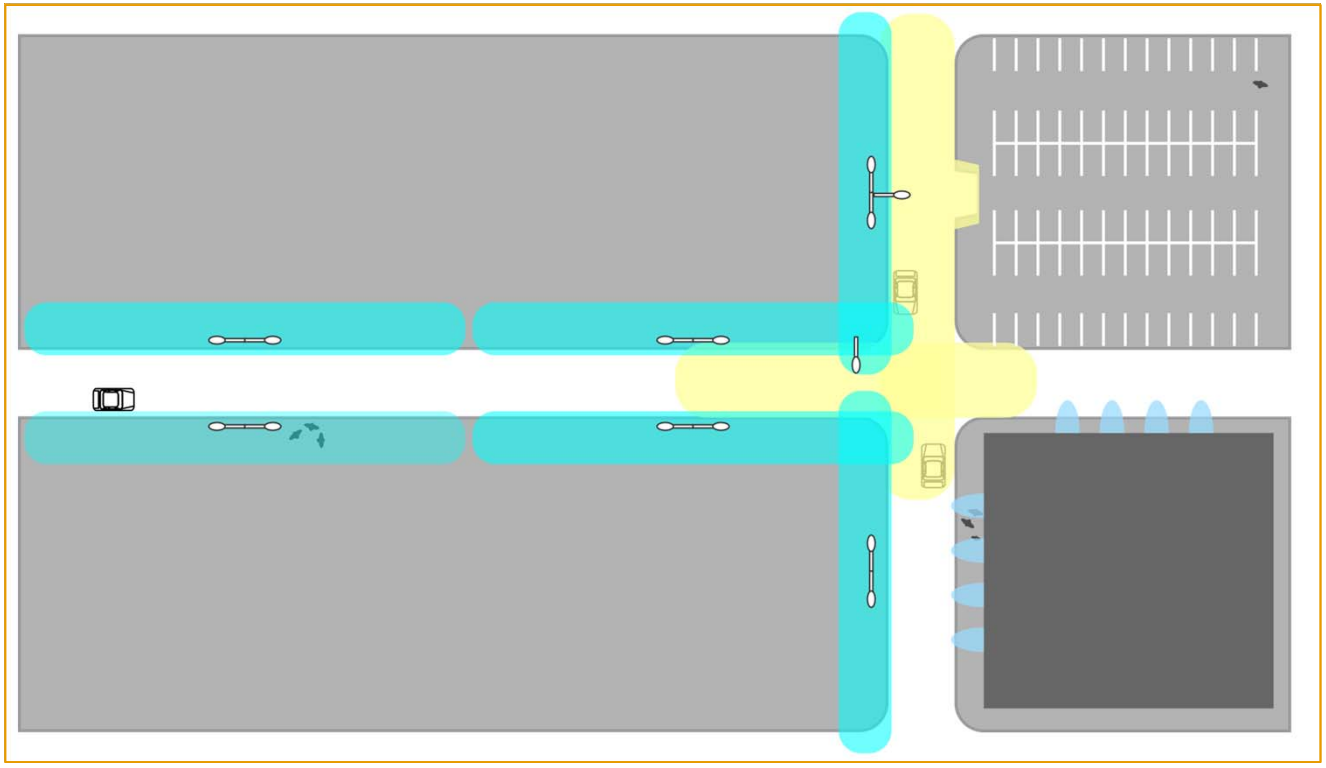
$$V_B(\lambda) = V(\lambda) + gS(\lambda)$$

$$g = f(E)$$

Sponsor: Philips Lighting

So, how do we illuminate?

Benefit: Personal security (scene brightness)



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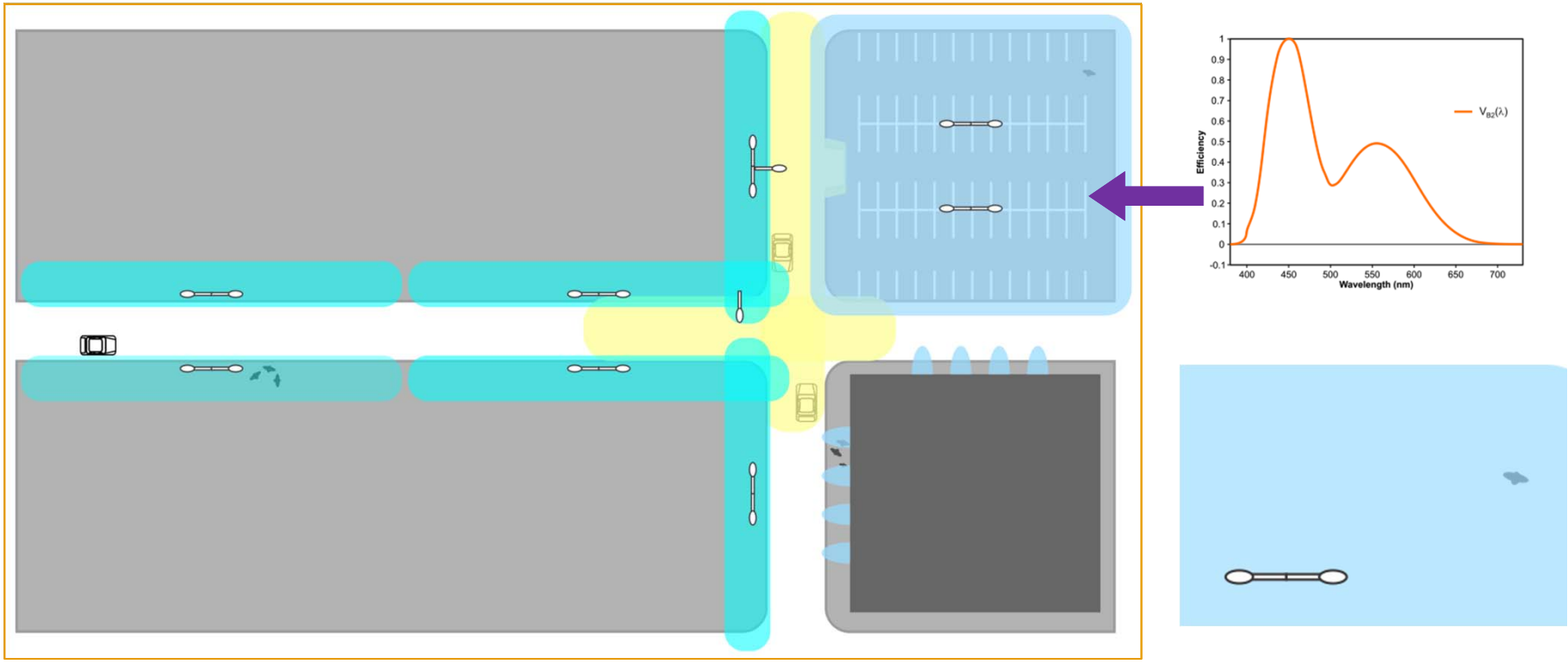


All cones (S + L + M)

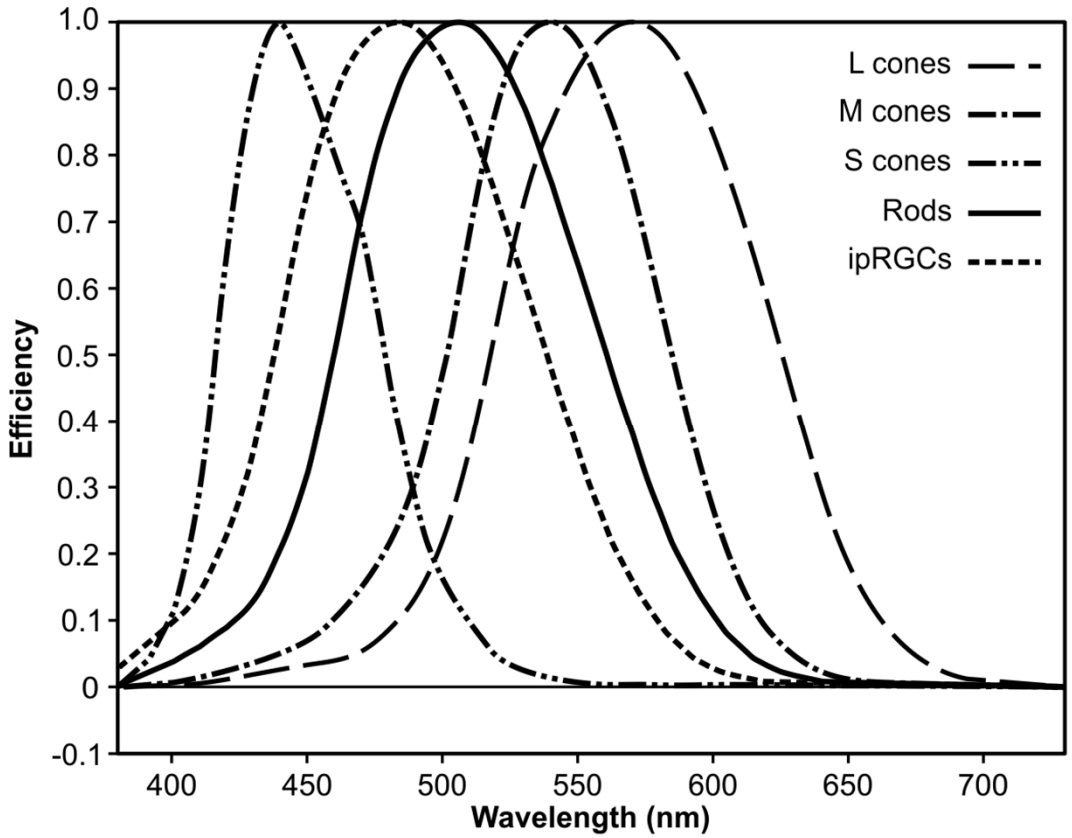
What matters to people is value

Value = benefit/cost

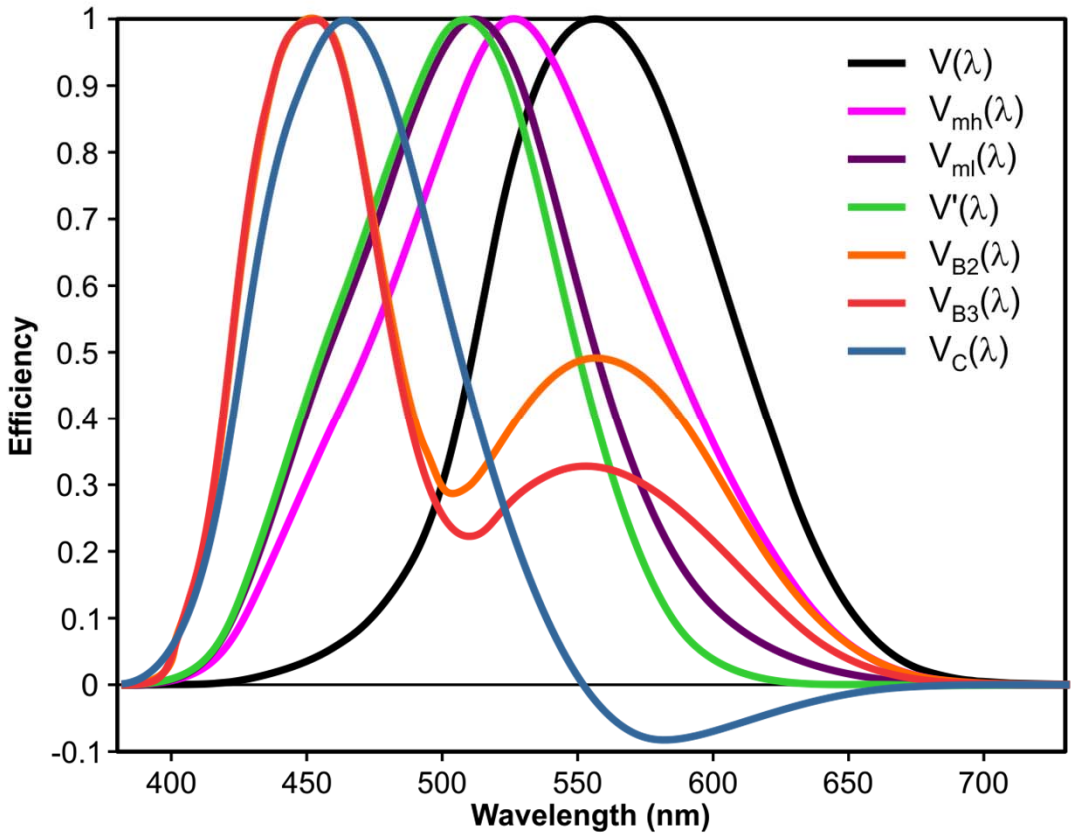
Benefit =

Images: www.osram.com
and www.photos.com

Building blocks for benefit metrics

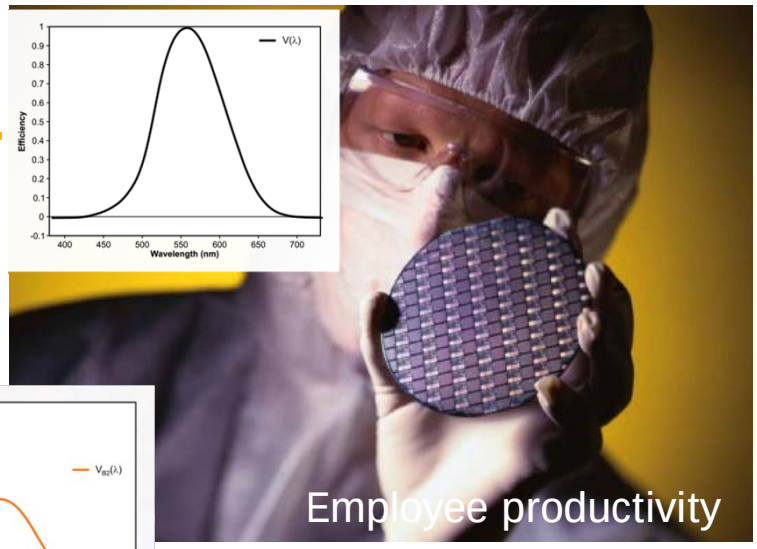


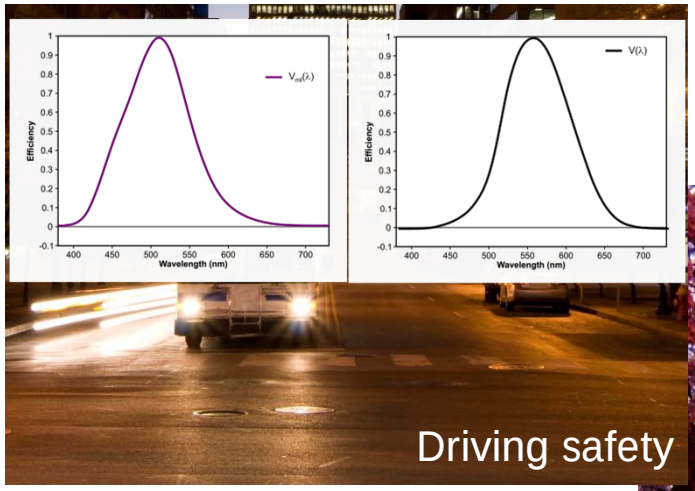
Benefit metric spectral weighting functions

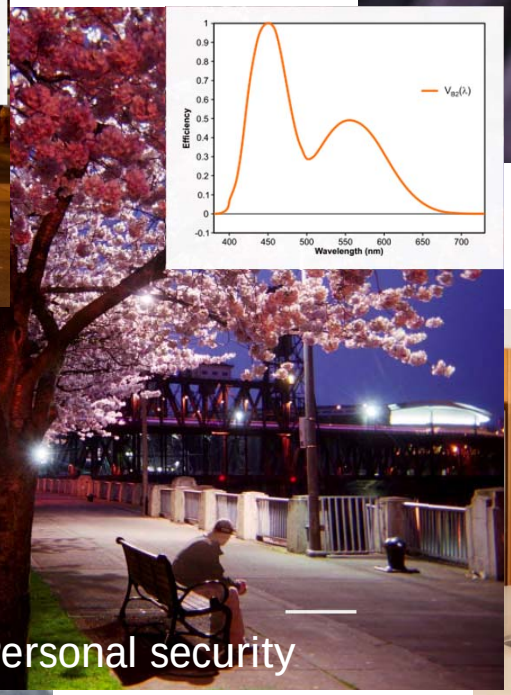


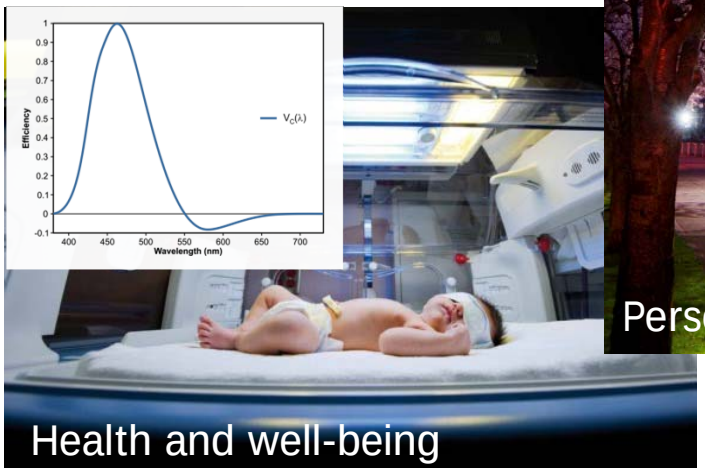
- Visual performance
- Brightness
- Circadian light

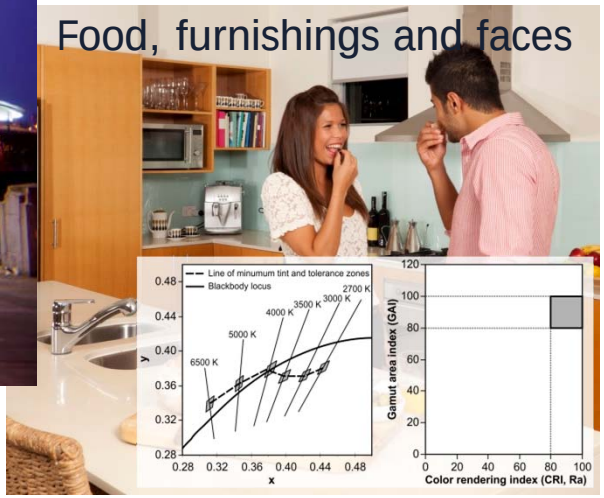
Different benefit metrics for different applications











Value = benefit/cost

Benefit metrics deliver greater value

Benefit	Benefit metric	
Driving safety, employee productivity	$V(\lambda)$, $V'(\lambda)$, $V_{mh}(\lambda)$, $V_{ml}(\lambda)$	Visual performance
Personal security	$V_{B2}(\lambda)$, $V_{B3}(\lambda)$	Brightness
Health and well-being	$V_C(\lambda)$	Circadian light
Food, furnishings and faces	GAI, CRI, white, consistency	Class A Color

These metrics have all the features of the lumen. All the rules of photometry, regulation and application can be equally applied to these functions (e.g., lm/m²).

Summary and conclusions

Pick the benefit desired

Select the best benefit metric

Design and regulate for the benefit

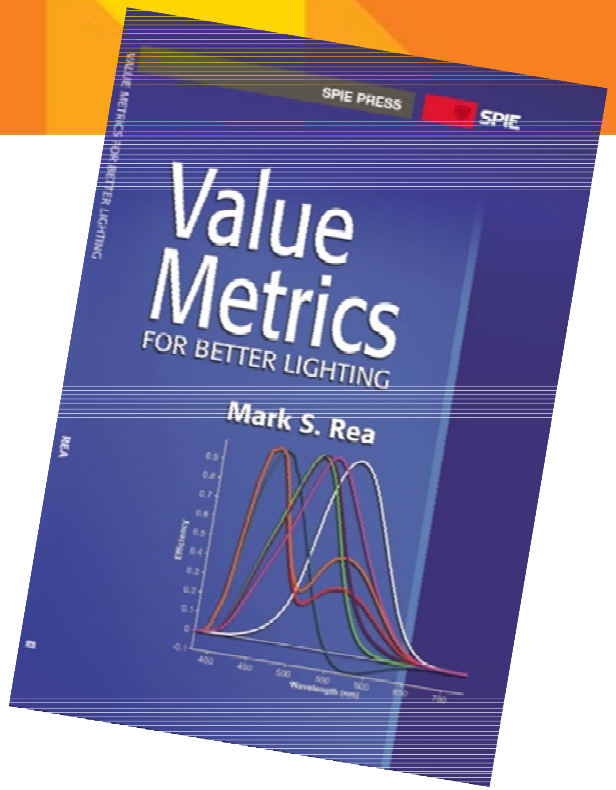
Results:

- Greater safety
- Greater personal security
- Lower energy use
- Less light pollution

And, the benefits can be monetized!

Illuminating ENGINEERING SOCIETY

Thank you.



Acknowledgment:

Dennis Guyon

Rea MS. 2013. *Value Metrics for Better Lighting.* SPIE Press, Bellingham, WA.